



USAF Academy's FalconSAT-3 Program

2007 Boulder Capstone Conference



United States Air Force Academy
Space Systems Research Center





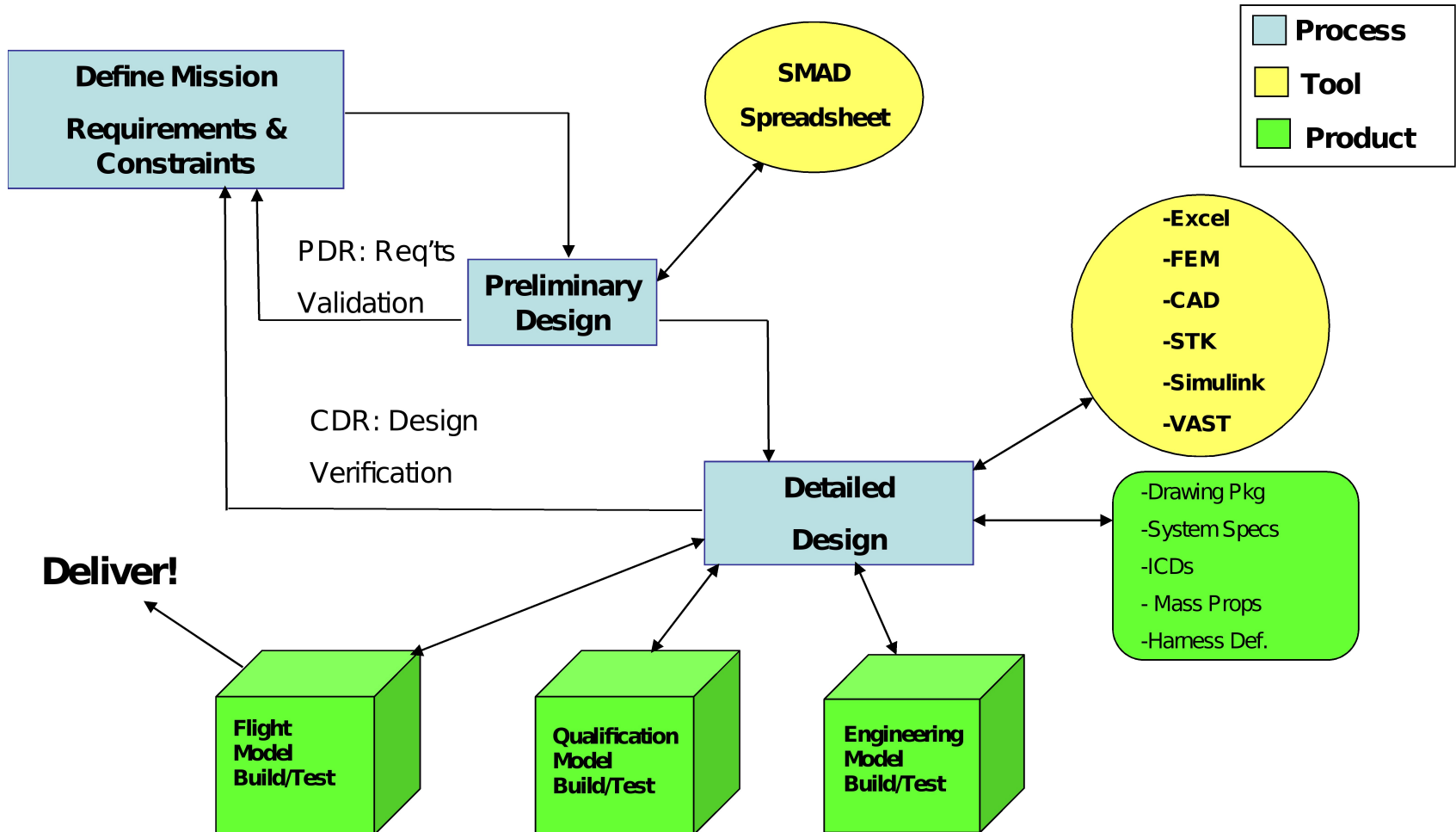
Overview

- Course Goals/Outcomes
- Program Background
- Current Program Status
- Expectations
- Organization





Systems Engineering Process





A436 Course Goals

- At the end of Small Spacecraft Engineering I (Astro 436) you will be able to:
 - Apply rigorous systems engineering practices to design, build, test and operate a spacecraft
 - Understand the fundamentals of spacecraft design and operations
 - Work effectively as part of a design team



A436 Course Outcomes

- To achieve these goals you will be required to complete and demonstrate an ability to do the following:
 - Critically analyze and trade-off program requirements & constraints (cost, schedule & performance) to develop realistic space system design options.
 - Understand and implement rigorous systems engineering practices.
 - Demonstrate independent learning by researching and assessing specific issues of spacecraft system performance and applying them to individual team tasks.
 - Demonstrate an ability to work effectively as a member of a Space Systems Program Office team, in both leader and follower roles, by: understanding program goals and objectives; identifying problems, analyzing alternatives and implementing solutions; diligently tracking and documenting decisions and analytical results; and successfully completing program milestones.



Program Goals

- Let Cadets “Learn Space by Doing Space”
 - Real-world, Hands-on Experience
 - “Cradle-to-Grave” of Space Missions
 - Mission Design
 - Payload and Subsystem Development
 - Assembly, Integration & Testing
 - Launch & On-orbit Operations
 - Program Management
- Support DoD space S&T objectives
 - Be a *Real* AF Program
 - Do *Real* DoD Science
(not just an academic program)
- Training a Cadre of Space Professionals





Spacecraft Open Architecture

- Partner with industry to transition open-architecture bus designs to COTS

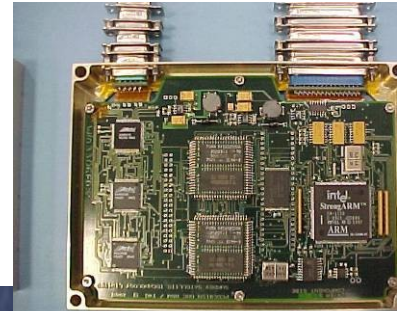
- SSTL, UK: SNAP hardware from 6.1 to GSA in 1 year
- SpaceQuest, USA: LatinSat hardware to GSA

- Open Architecture

- Basic spacecraft bus provides: power, data handling, communications, payload/subsystem integration architecture
- Defines a stable, open system design with simple interfaces

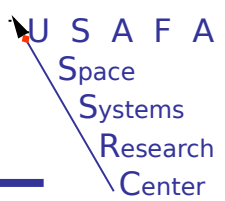
- Focus program

- Responsive Space
- Space science experiments
- Structure, thermal, attitude control
- Integration, testing, operations
- Systems engineering





Space Systems Research Center Infrastructure



- Extensive mechanical/electronics facilities
- Space Simulation Chambers
- Ground Station
- Clean room (class 100,000)
- Vibration/Loads test stand
- FalconSAT Avionics & Simulation Testbed (FAST)





Approach: System Development

- **FalconSat Avionics Simulation and Testbed (FAST)**

- Forms the foundation of FalconSat-N and provides an environment for software, subsystem, and payload development and testing

- **Engineering Model**

- Subjected to the most rigorous and extensive environmental and functional testing

- **Qualification Model**

- Subjected to Qualification-Level environmental test conditions.

- **Flight Model**



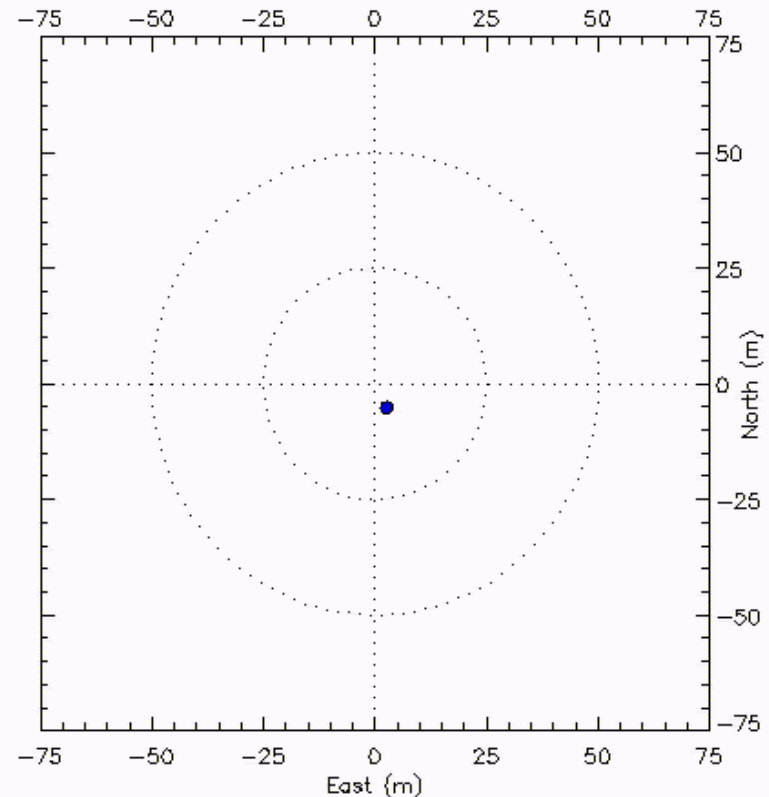
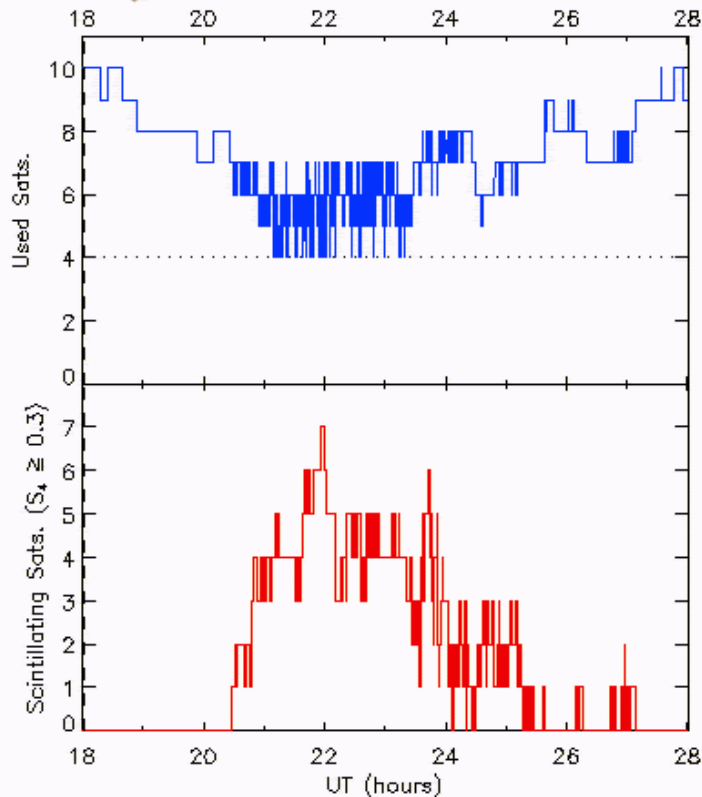


Effects of Scintillation on GPS



GPS Position Error

Ascension Island, 03/16/2002



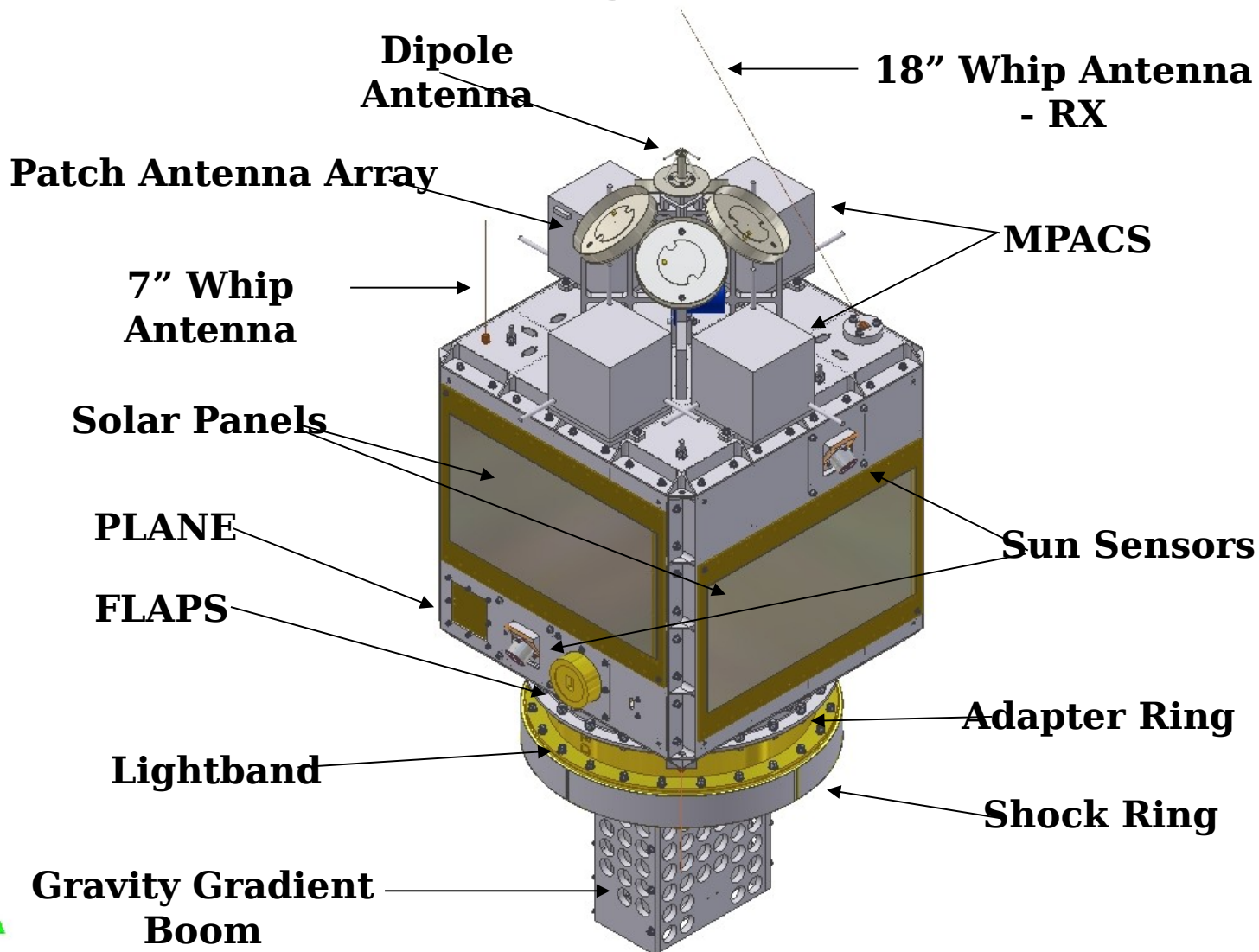
Time: 18:01 UT Used: 10 Scint: 0 CEP: 0.1m





FalconSAT-3 External View

Figure





FalconSAT-3 Payloads and Mission

- FalconSAT-3 meets DoD science objectives with three payloads
- The third SERB payload also meets DoD technology objectives by demonstrating new thruster technology

- Orbital Parameters:

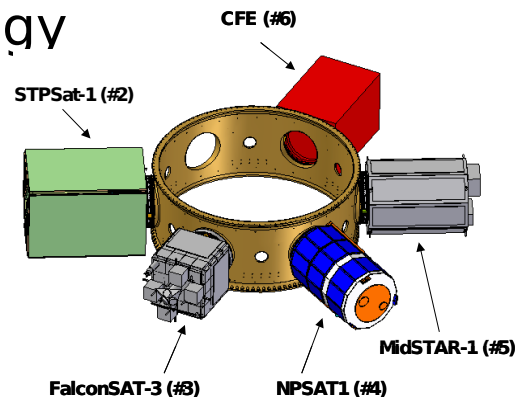
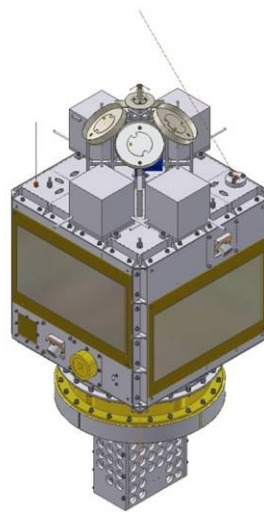
- Semimajor Axis – 560 km
- Inclination – 35.4 deg
- Eccentricity – Near Circular

- **FLAPS**

- Investigate plasma morphology
- Demo new instrument
- Developed by SPARC/NASA/APL

- **PLANE**

- Investigate ambient plasma
- Demo new sensor
- Developed by SPARC
- AFOSR tie-in



- **Shock Ring**

- AFRL/VS tech demo
- High freq vibration isolation

- **MPACS**

- Demo/characterize new propulsion technology
- AFRL/PR
- m-PPT invented, modeled under AFOSR funding



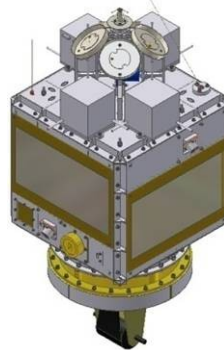
FalconSAT-3 Test Program

SEM



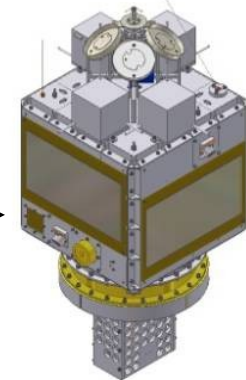
new boom

OM



new boom

FM



- May 03, Jan 04
- Dynamic testing
 - verify design
 - verify workmanship
- determine shock ring performance with lightband

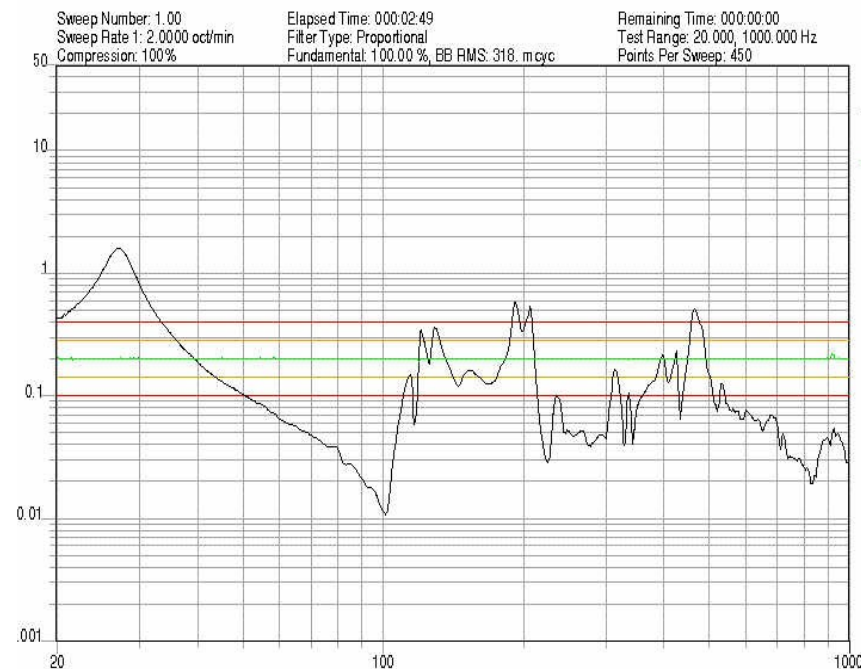
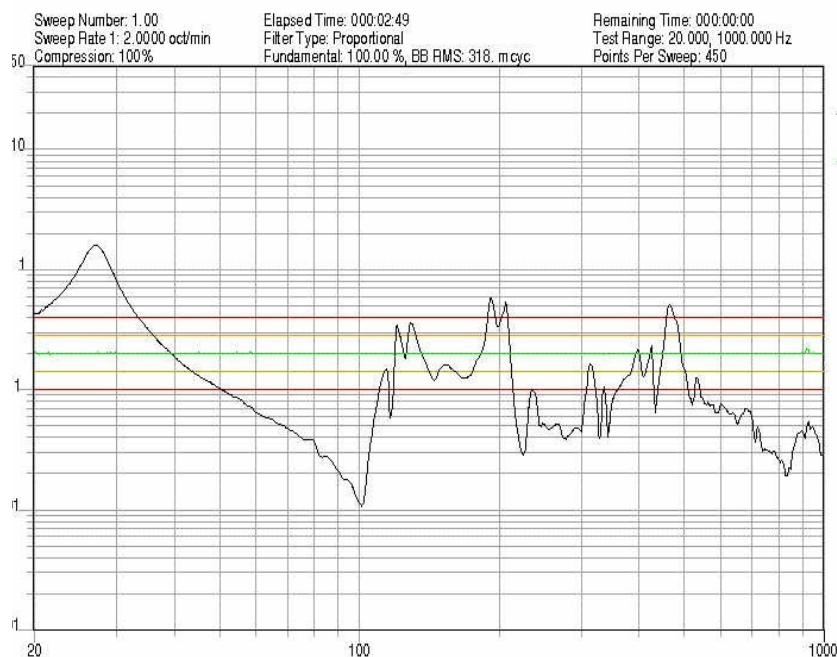
- Feb 05
- Dynamic testing
 - verify design
 - boom failure
- Thermal-Vac
 - identify component problems

- Apr 06, Jun 06
- Dynamic testing
 - verify assembly
 - qualify boom
- Thermal-Vac
 - accept components



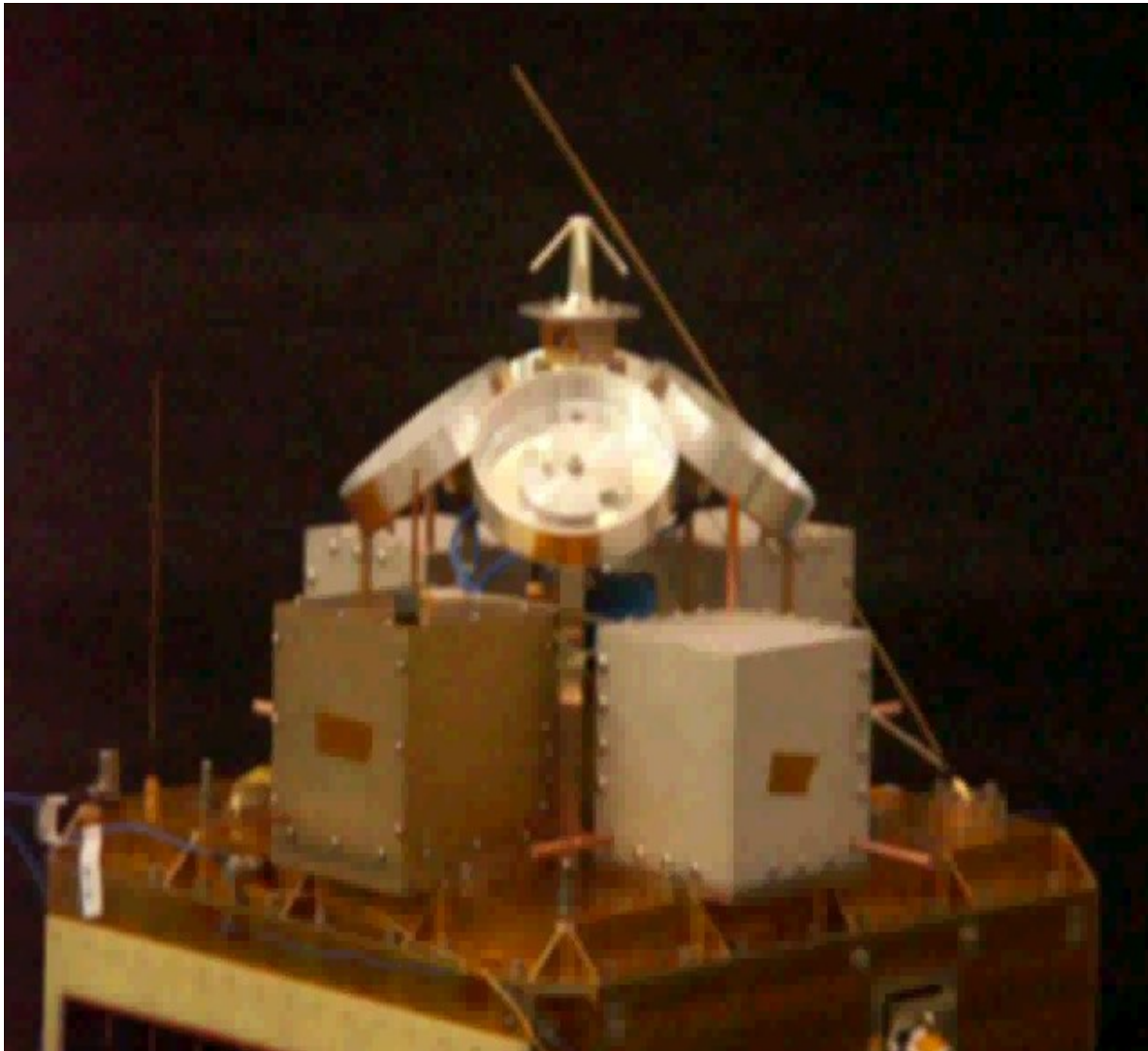
FalconSAT-3 AIT - Vibration

- Functionality tests conducted on all systems except MPACS & FLAPS due to vacuum requirements
- All telemetry values nominal





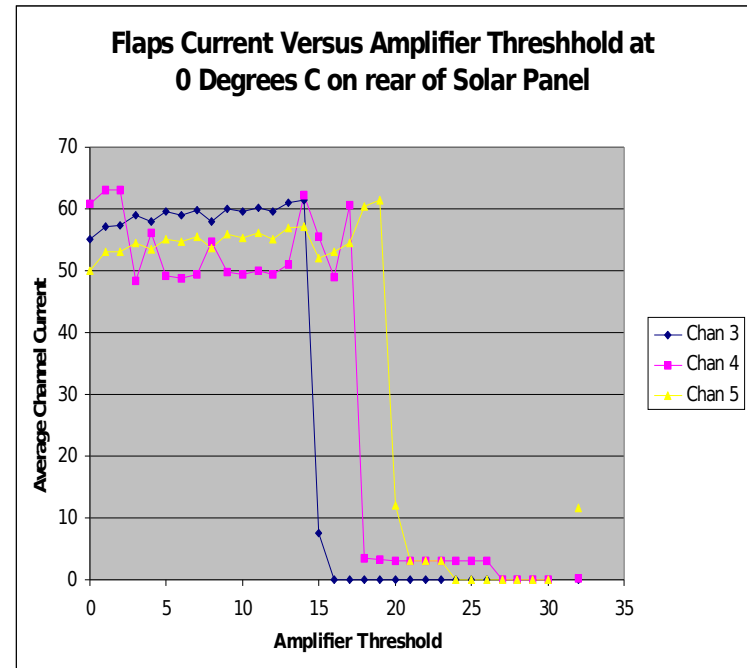
FS-3 QM





FalconSAT-3AIT - Thermal Vacuum

- 3 Cycles at +40 deg C with 1st lasting 6 hours
- 3 Cycles at -10 deg C with 1st lasting 6 hours
- 10 hours between cycles
 - Functionality tests lasting 2 hours conducted for each cycle
- PLANE & FLAPS payloads, communication, power (batteries & solar arrays), sun sensors, magnetorquers, magnetometer, WOD file creation
 - Successful throughout entire campaign
 - Battery discharge characterized at -10 & +40 deg C
 - Communication links characterized as a function of temperature



Launch

- Launch day 8 March
 - Astro cadets sent to Cape to watch live launch
 - Topped up batteries, no anomalies noted
 - Launch party in USAFA Ground Station
 - FalconOps trip to ULA





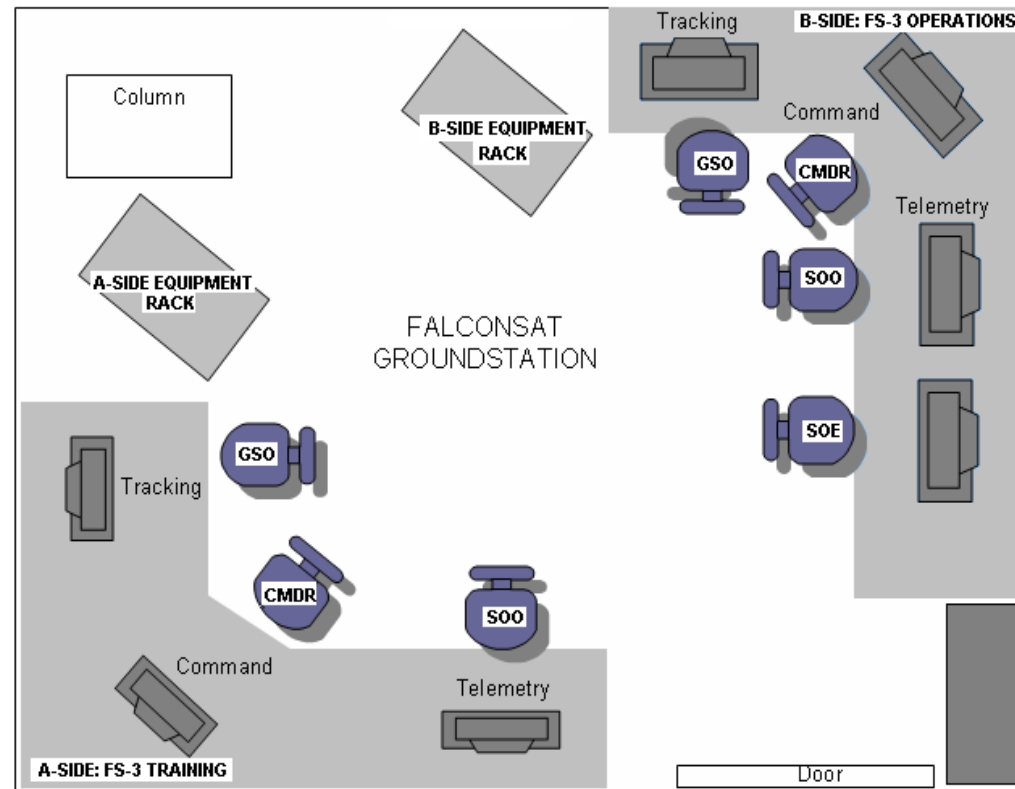
Crew Structure and Responsibilities

CREW POSITIONS:

- Crew Commander
- Satellite Operations Officer
- Ground Station Operator
- Satellite Operations Engineer

CREW SHIFT RESPONSIBILITIES:

- Pre-Contact
- Satellite Contact
- Post-Contact
- **DATA DISTRIBUTION**





Mission Phases Post Launch

■ Commissioning

- Determine basic health
- Determine sub-system health
- Activate software
- Test all software tasks
- Verify all software tasks
- Transition to normal operations

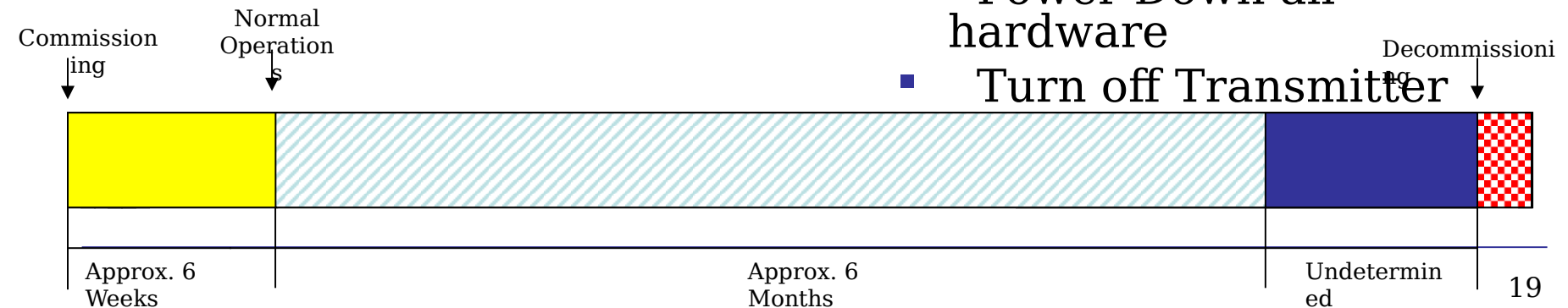
■ Normal Operations

- Download telemetry data
- Download payload data
- Maintenance operations

■ Extended Operations

■ Decommissioning

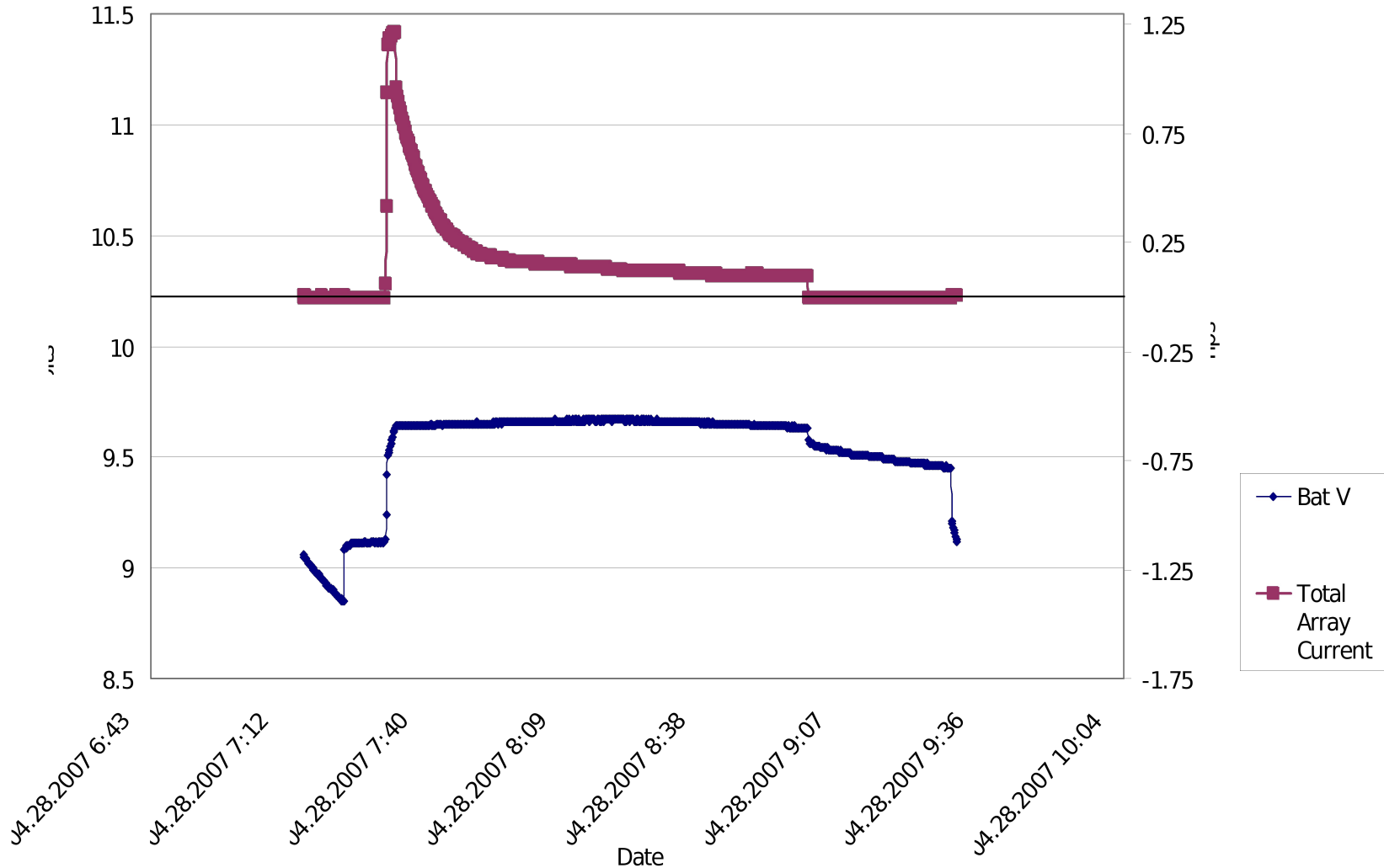
- Power Down all hardware
- Turn off Transmitter





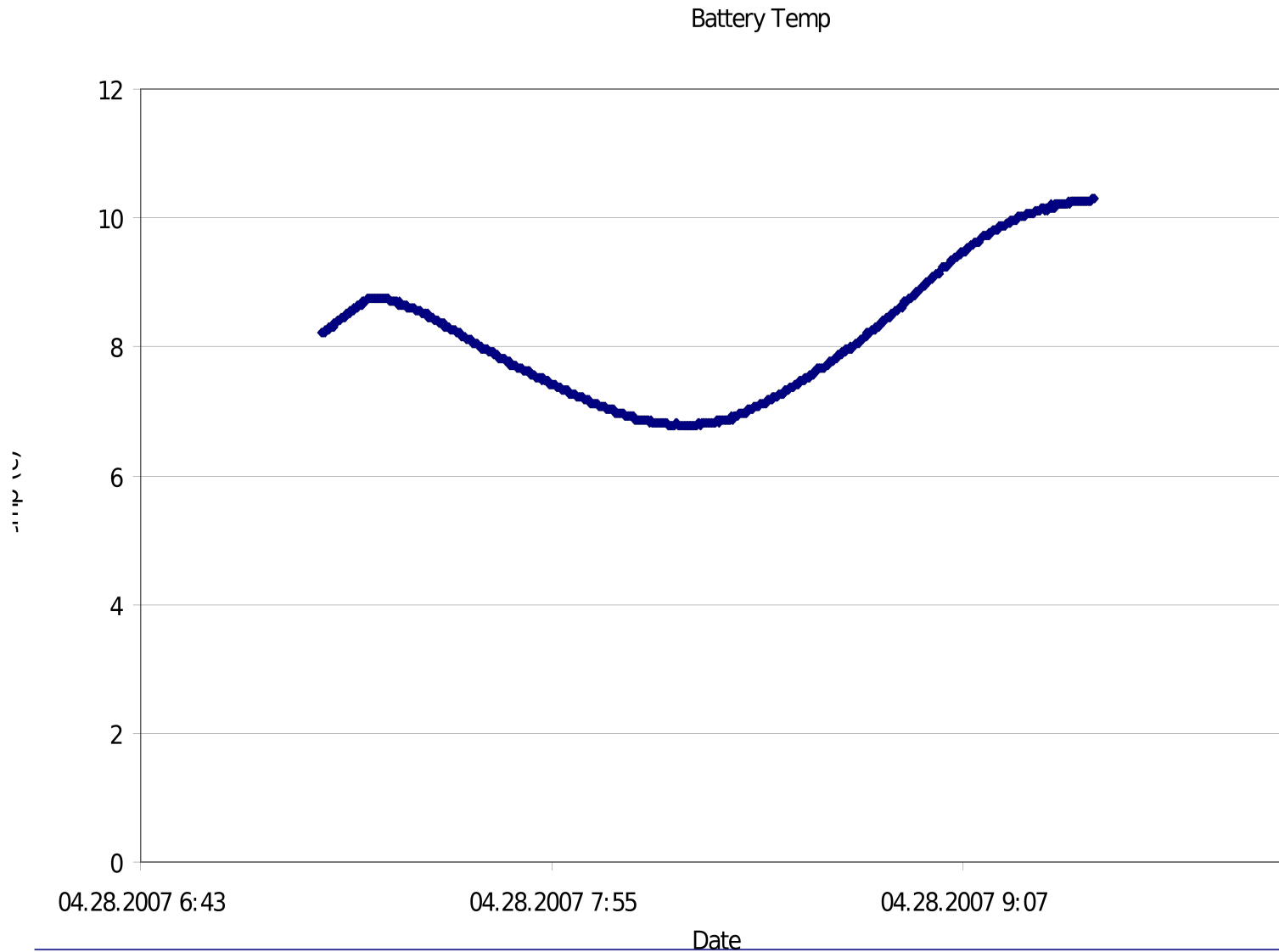
Spacecraft Power Nominal

Voltage vs Total Array Current



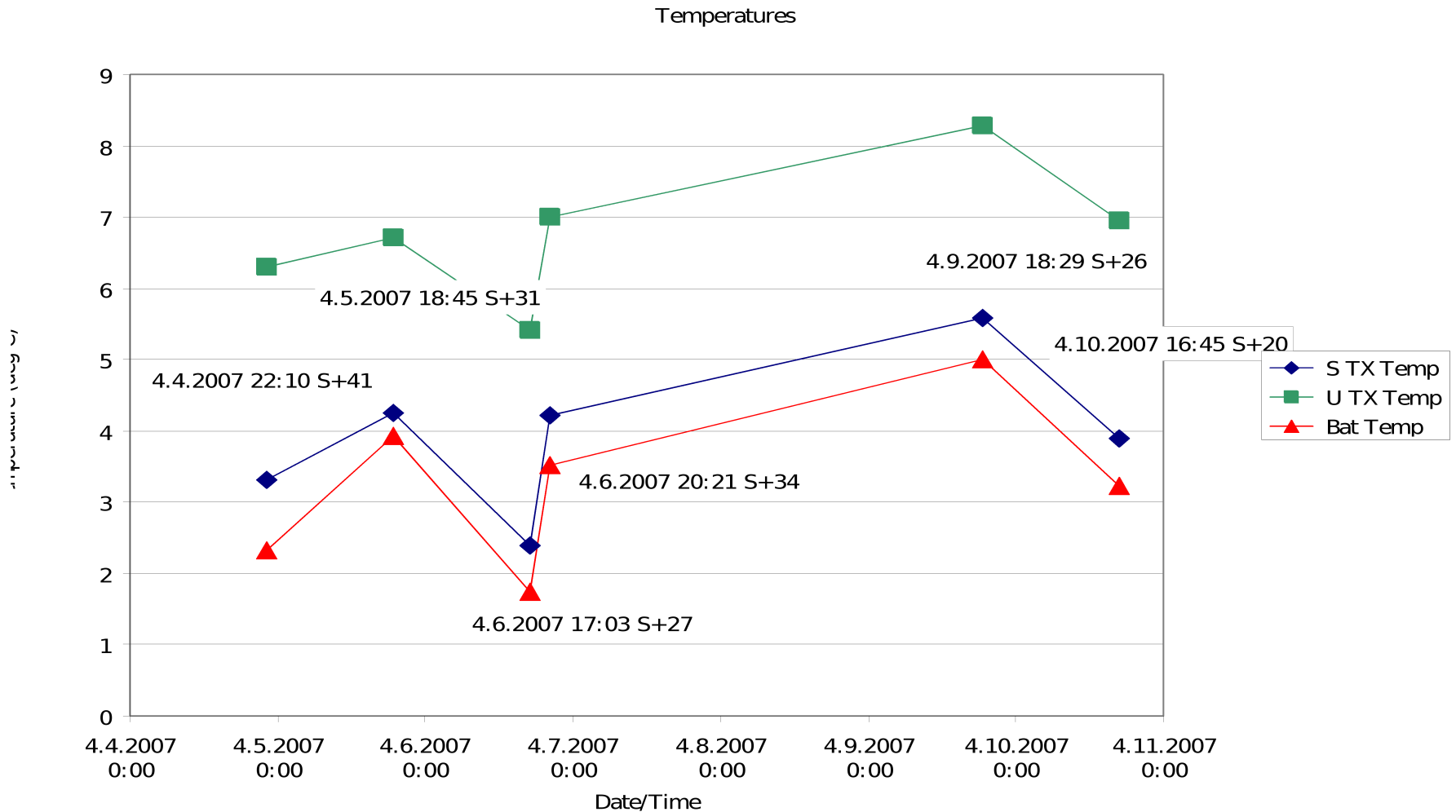


Battery Temperature Nominal





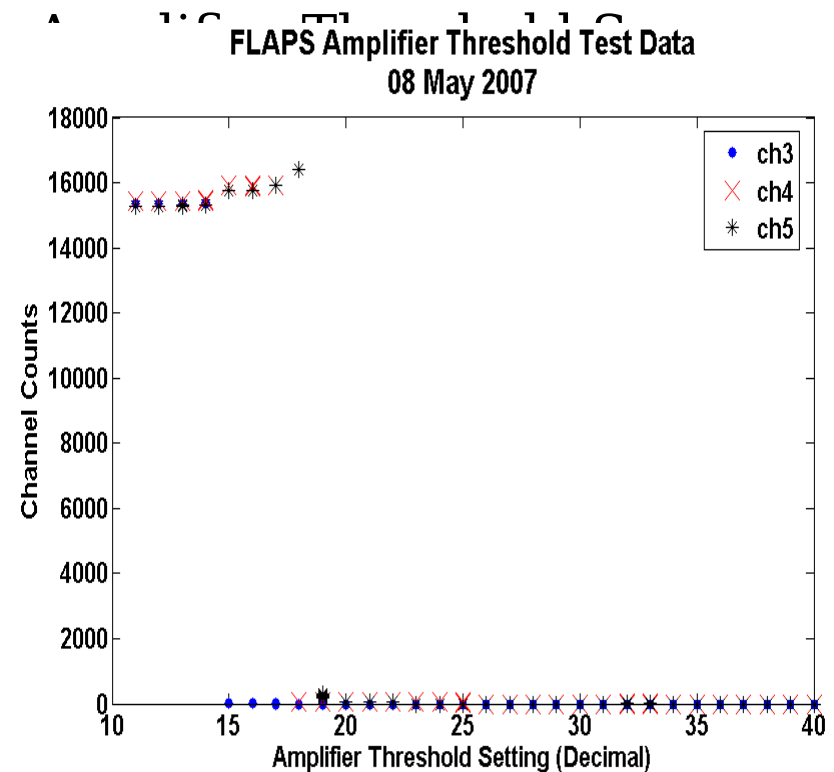
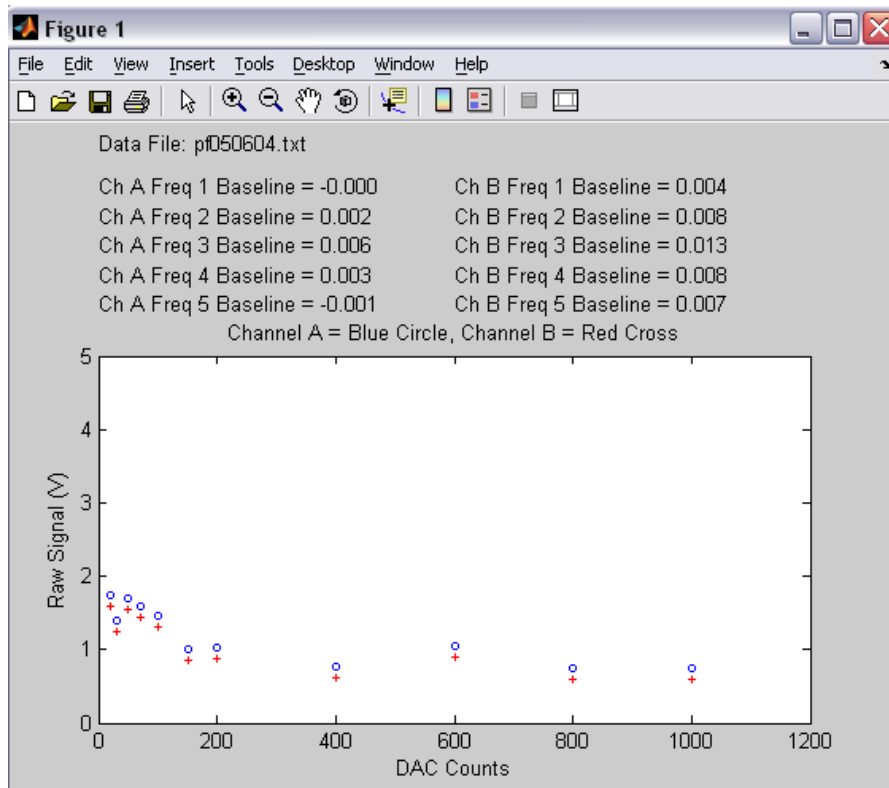
Thermal Design Verified





FS-3 Payload On-Orbit Checkout

PLANE FLAPS

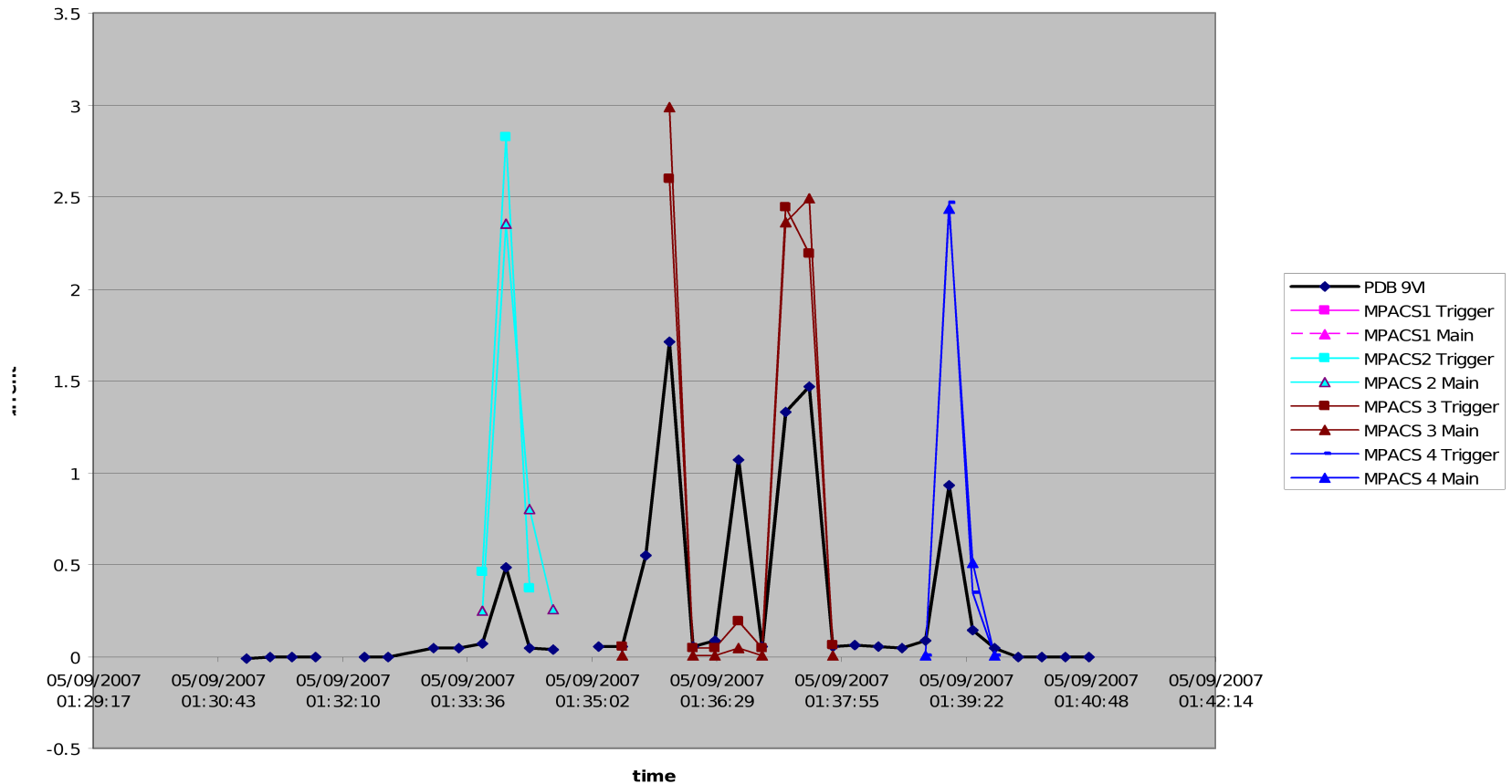




MPACS

- All MPACS Tubes Fired Successfully

MPACS and PDB Data





Data Use

- Primary User: USAFA Physics Department
 - Will digest data and create detailed models
- Who else will use the data?
 - Air Force Research Labs (AFRL)
 - NASA
 - Air Force Space & Missile Center Space Test Program (SMC/STP)
 - APL
 - Boeing
 - United Launch Alliance
 - SpaceQuest
 - Surrey Institute
 - Busek (MPACS)
 - CSA
 - Air Force Office of Scientific Research (AFOSR)
 - And more...



FalconSAT-5 Science Motivation

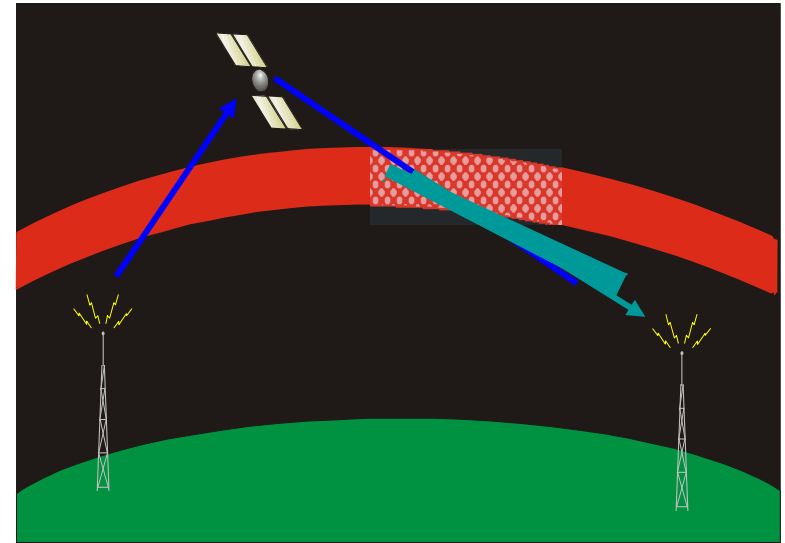
Problem: Need RF and plasma measurement correlation

USAFA cadets & faculty/AFRL scientists improve ionospheric models

iMESA
characterizes
ambient
plasma
environment

WISPERS
characterizes
perturbed plasma
environment from
thruster firings

RUSS characterizes VHF signal
distortion to supplement in situ
plasma measurements



*Turbulence in the ionosphere
distorts VHF signal*

Solution: FalconSAT-5 SERB Experiments improve space situational awareness

Payload synergy supports science objectives for a well-integrated mission



FalconSAT-5 Experiment Objectives

■ WISPERS

- Measure ions resulting from ion source to validate USAFA and AFRL/PR plume models

■ iMESA

- Detect the temperature and density of ambient ions to validate ionospheric data assimilation models

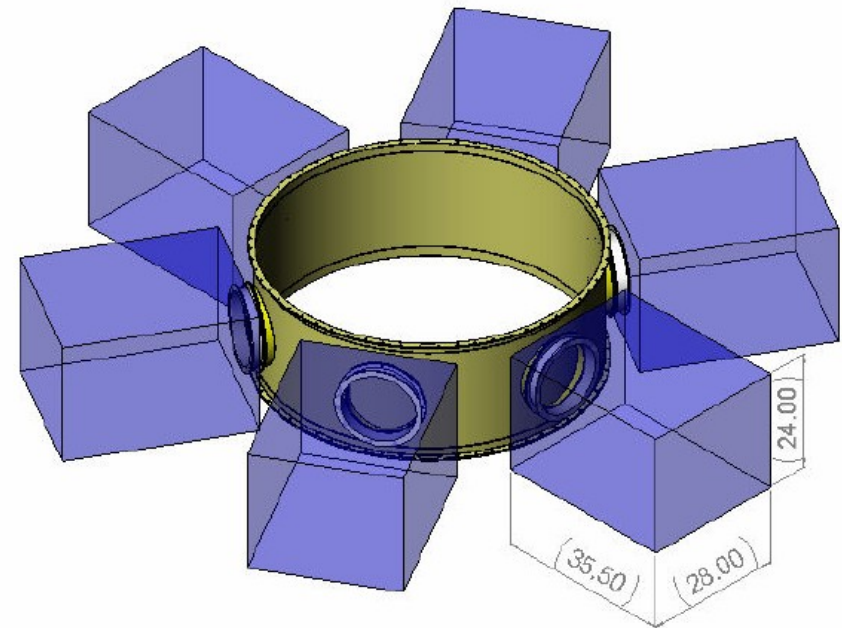
■ RUSS

- Received VHF Signal Strength meter
- Characterize VHF signal distortion to improve ionospheric models

Design Constraints

- FalconSAT-5 designed to be compliant with the ESPA constraints
- Key Constraints:

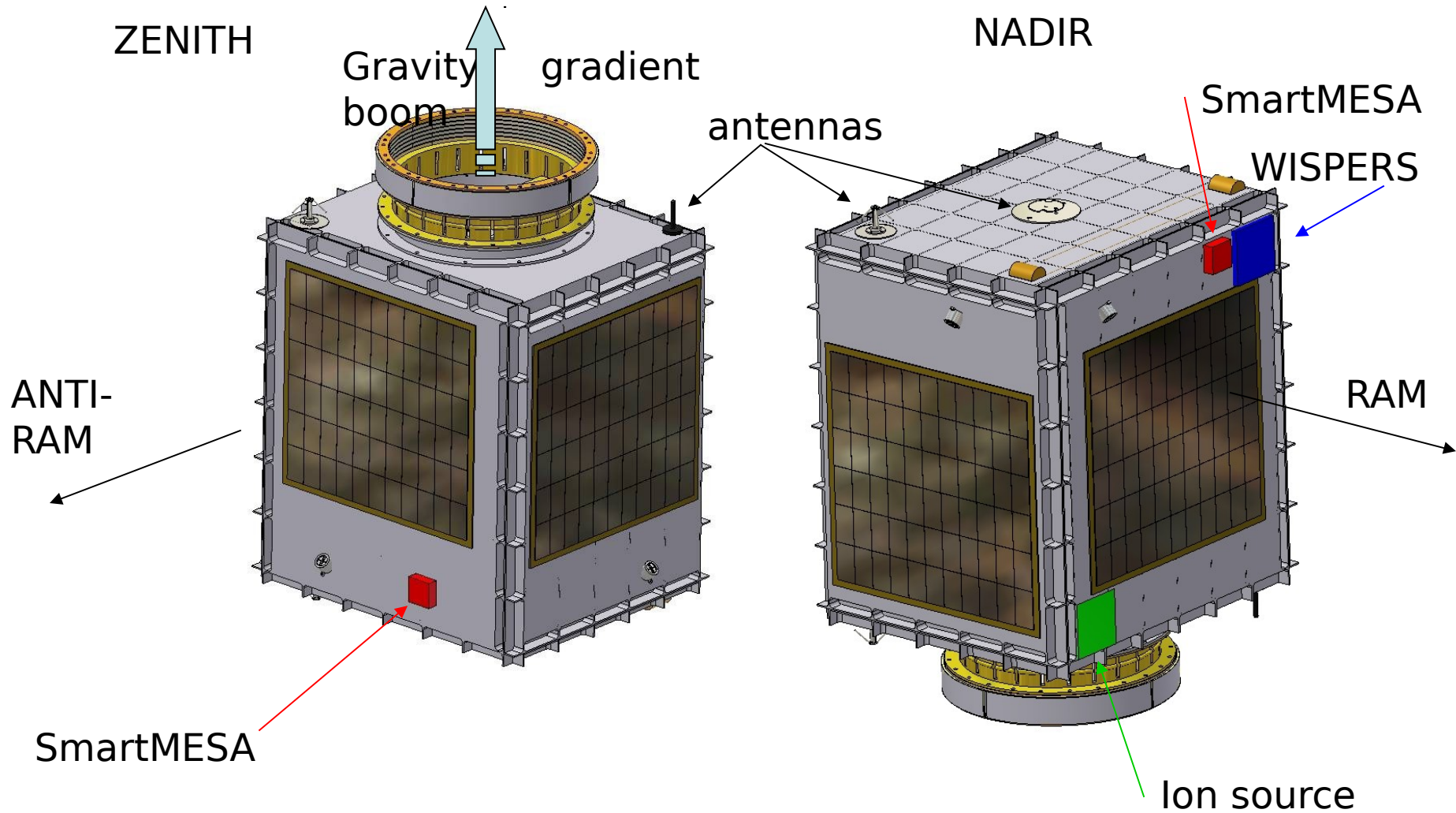
Envelope	60.96 cm x 71.12 cm x 96.52 cm
Loading	8.5g lateral and axial
Mount	31.8 cm mounting ring
Mass	<181kg
Frequency	>35 Hz
Internal boom configuration	within 1.27 cm of local z axis
CG	within 50.8 cm of interface plane



- Aids integration with potential users
- Satisfies Minotaur 1 or Minotaur 4 User's Guide**

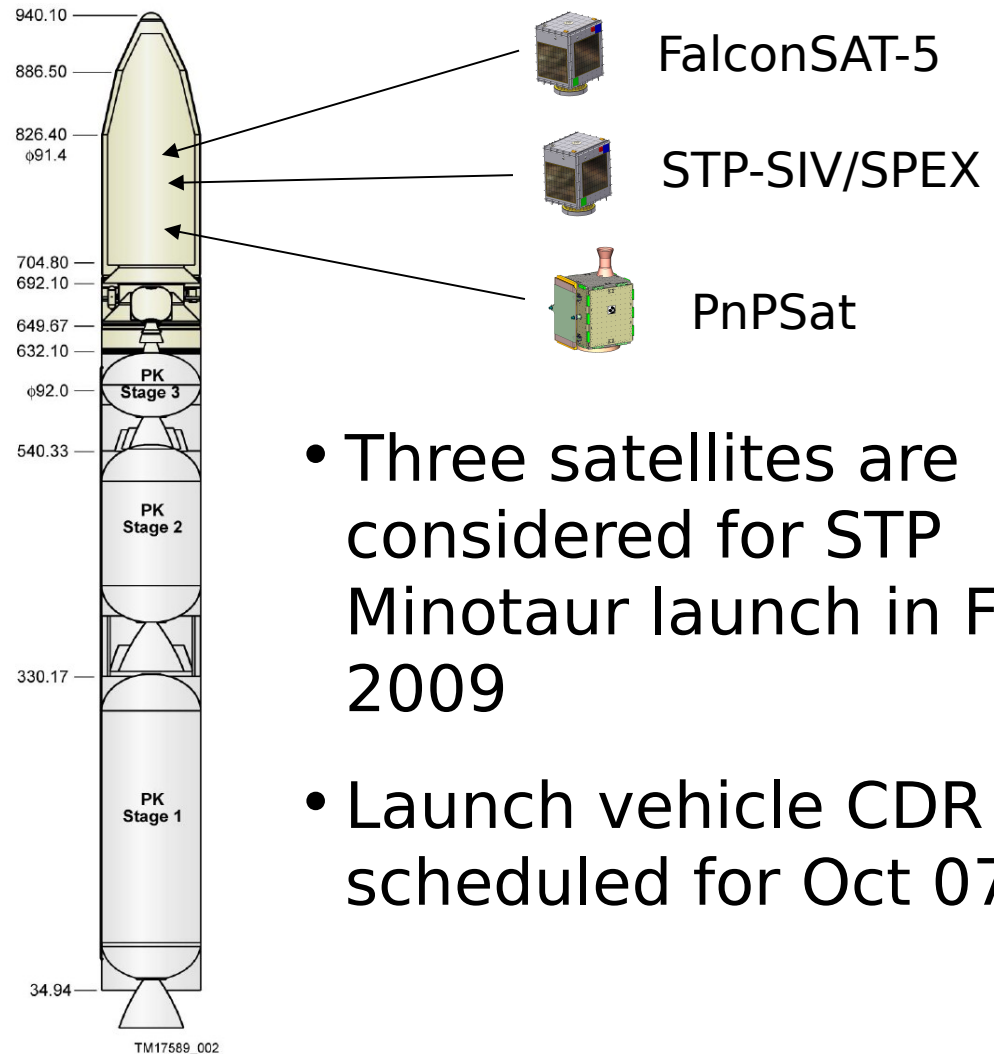


Satellite Configuration Overview





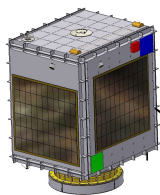
STP Minotaur Mission



- Three satellites are considered for STP Minotaur launch in Fall 2009
- Launch vehicle CDR scheduled for Oct 07

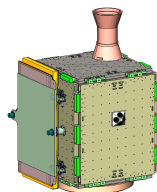
Integrate Three Satellites

FalconSAT-5



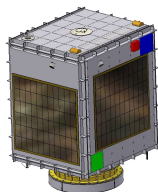
- ~ 24" x 28" x 36"
- three payloads

PnPSat



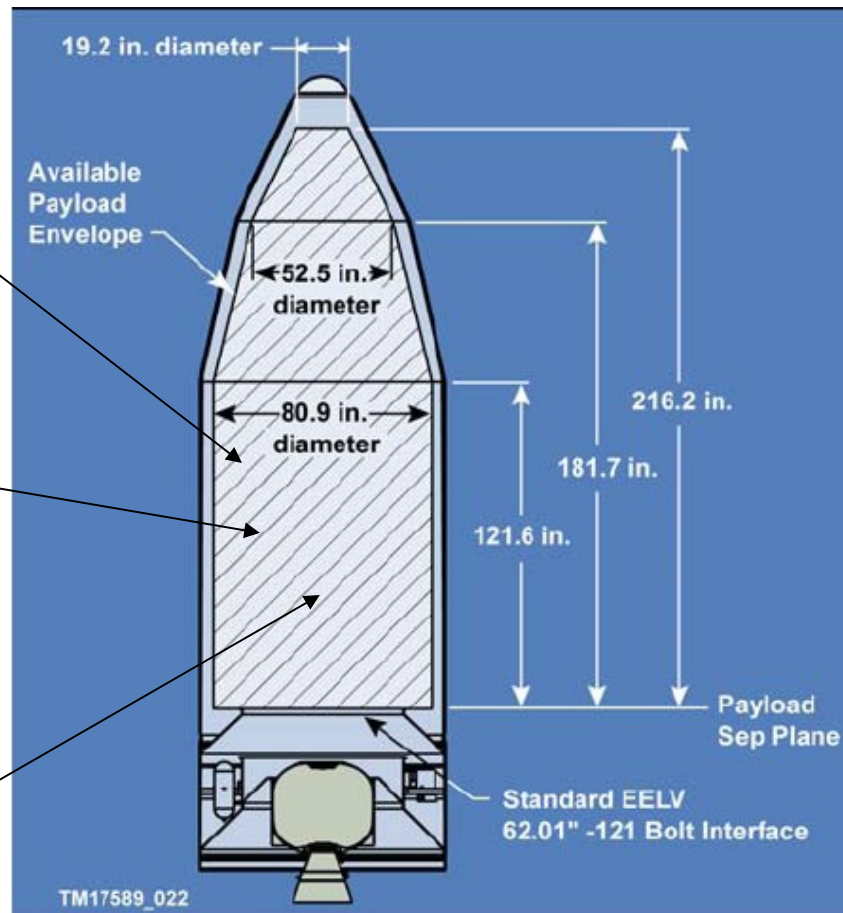
- ~ 24" x 28" x 30"
- four payloads
- (one USAFA)

SIV/SPEX



- ~ 24" x 28" x 30" (?)
- one payload (?)

?





FalconSAT-5 Schedule

class	Fall 06	Sprin g07	Fall 07	Sprin g08	Fall 08	Sprin g09	Fall 09	Sprin g10	Fall 10	Sprin g11
2007	Design/test SEM test PDR									
2008			Design/test CDR QM test							
2009					Integrate/test AIT FM test					
2010							Launch/opns launc commission			
2011									operations operations reports	



What are we looking at?

- The Deliverables represent the Product
 - Tangible items that will survive past May 2005
 - 2005 legacy!
- The Master Schedule represents the Process
 - A road map that tells how to get there from here
 - Step-by-steps tasks that lead to the product
 - Time and order dependence!
- To complicate things
 - Lots of things happening at the same time
 - Different teams pulled in several directions at once
 - Individuals with multiple responsibilities



Expectations

- What you can expect from the faculty!
 - Provide clear vision of the big picture (What's the mission?)
 - Provide a specific road map/process (How do we accomplish it?)
 - Provide specific guidance of responsibilities (What's my job?)
 - Provide resources needed to do the job (Money, manpower, information)
 - Provide timely feedback (How am I doing?)



Expectations (cont.)

- What I'd expect of a 2Lt
 - Understand the mission
 - Know your job
 - Committed to getting the job done
 - Take responsibility for organizing your time & resources
 - Provide timely feedback on how things are going
 - Give advance warning if things are going off course

- *"Nothing Great is Easy" – Capt Matthew Webb*



Expectations In this Program

- *“Champions don’t make excuses.”*
Freda Streeter
 - Understand the Program Deliverables
 - If you don’t why we’re doing something—ask!
 - If there is a better way—suggest it!
 - Understand the Master Schedule
 - This is your schedule!
 - It defines your process
 - If you don’t why we’re doing something—ask!
 - If there is a better way—suggest it!
 - If there is something missing—tell someone!
 - Know how your efforts fit into the big picture—there is no dead wood!
-



Mgt Team Responsibilities

- **FalconSAT-3 Program Manager**
 - Total System Performance Responsibility (TSPR) for FS-3 Mission
 - Cost/Schedule/Performance
 - Program Milestones, e.g. Flight Readiness Review (FRR)
 - Logistics Plan: Integration to Launch
 - Supports Program PR
- **FalconSAT-4 Program Manager**
 - TSPR for FS-4 Mission
 - Cost/Schedule/Performance
 - Program Milestones
 - Supports Program PR
- **Chief Engineer (TBD)**
 - Serves as Program Systems Engineer (FS2 + FS3 +FS4)
 - Total system technical insight/oversight
 - Identify and resolve system interface and technical issue
 - Identify system performance trade-offs to PM's and PD and helps to resolve
 - Supports Program PR
- **Assistant Program Director for MIS**
 - Manages FalconSAT/FalconLAUNCH management info systems (website, dbase, project, etc.)
 - Works with PMs to collect, collate and disseminate program data (% complete, action items, hours logged)
 - Works with PD and PMs to develop and manage program budget and procurement
 - Supports Program Travel and Logistics Planning/Execution
 - Supports Program PR
 - Documentation!
- **FalconOPS Program Manager**
 - Ensures Ops team is ready for FS-2 flight
 - Commissioning, Normal Operations
 - Ops Plan for FS-3
- Ops, Avionics and Mech team leads also on mgt team



Operations Systems Team Responsibilities

- FS-3/4 Operations Planning
 - Mission Planning and Analysis
 - Orbit/pass planning
 - Link budgets
 - Power budgets
 - Thermal system analysis/design
 - ADCS simulation, algorithm development and software requirements definition
 - Payload planning and software req'ts definition
 - VAST
 - Operations Plan Development
 - Frequency coordination/mgt
 - Ground station & EGSE design
- FS-3/4 Software Design/Development/Testing
 - Housekeeping Software
 - ADCS Software
 - Payload Software
 - Ground Ops Software
- Facilities Mgt
 - Ground station
 - Clean room
 - EGSE
- Support other program activities as required
 - Provide inputs to program documentation
 - Support Mech team in Fabrication
 - Support AIT, ESPA Integration and Science WGs



Avionics Systems Team Responsibilities

- **Primary design & acquisition responsibility system avionics hardware**
 - Define and manage payload/subsystem specifications and documentation
 - Define and manage payload/subsystem electrical and mechanical interfaces
 - “Face to the customer/contractor” for all avionics hardware
 - Develop/manage payload/subsystem Interface Control Documents (ICDs)
 - Define subsystem acceptance/qualification/flight testing requirements
- **System Avionics Hardware =**
 - Power subsystem hardware (batteries, power module, solar panels)
 - Data Handling Subsystem Hardware (IFC)
 - Communications Subsystem Hardware (RX, TX, Antennas)
 - Attitude Determination & Control Subsystem (ADCS) Hardware (Boom, Magnetorquers, Magnetometer, Sun Sensors, Wheel)
 - Payload Hardware (MPACS, FLAPS, PLANE, Boom)
 - Harness
 - FS-4 support
- **Support other program activities as required**
 - Provide inputs to program documentation
 - Fabricate components for Mech Team
 - Support AIT, ESPA Integration WGs



Mechanical Subsystems Team Responsibilities

- Design and build all spacecraft structures and mechanical systems
- Develop and maintain system drawing package
 - CAD Models
 - Mechanical drawings
 - Parts list
- Develop and maintain system mass properties
- Manage all payload/subsystem mechanical interfaces
- Support launch vehicle integration/interface
 - FEM
 - Stress analysis
 - Fit checks
 - LV ICD
- Design, fabricate, assemble, test, deliver FS-3 MGSE
- Validate QM assembly plan
- Fabricate FM Structural Components
- FS-4 support
- Support other program activities as required
 - Provide inputs to program documentation
 - Support AIT, ESPA Integration and Science WGs

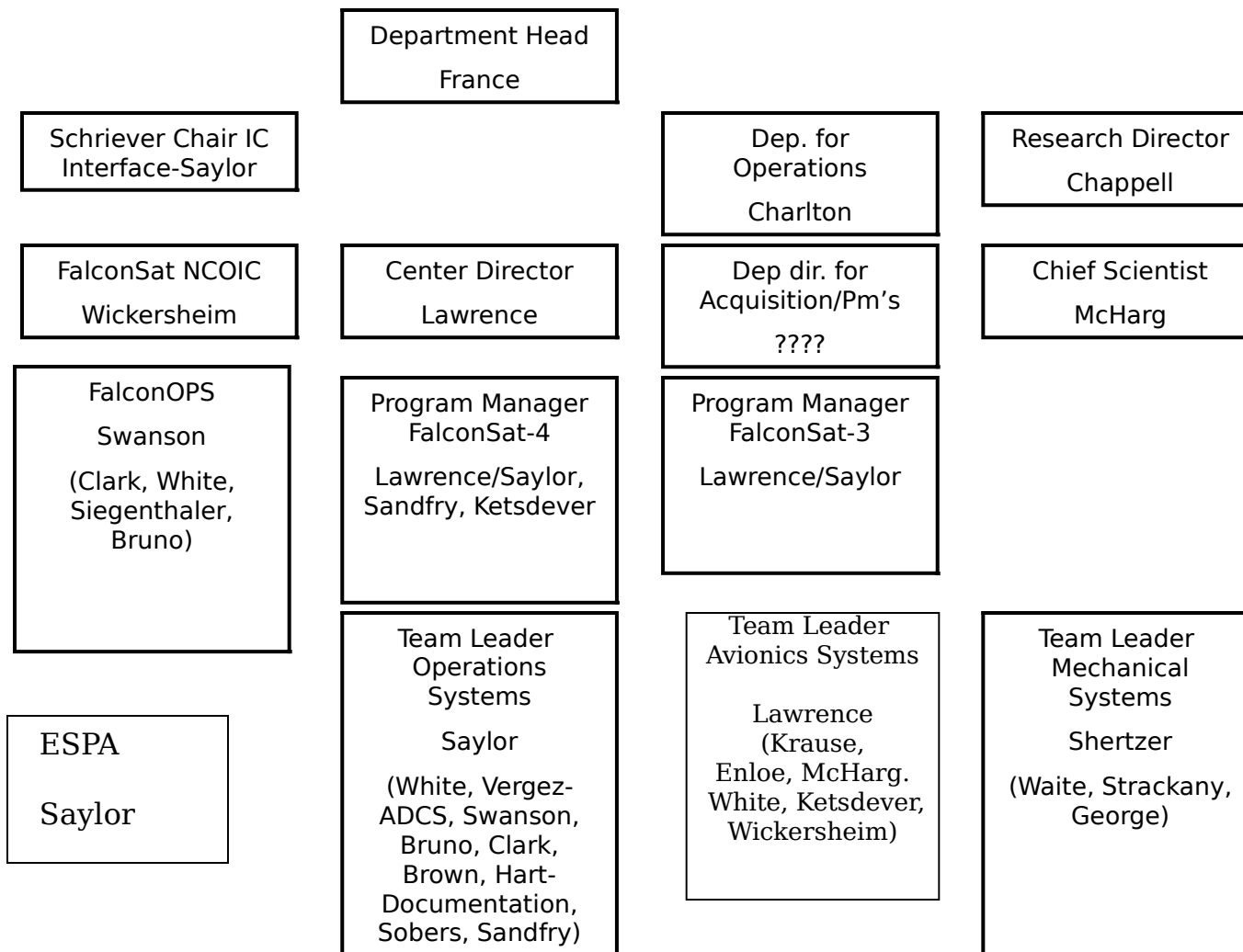


AIT/Payload Working Group

- Focal point for program assembly, integration and testing (AIT) requirements and activities
 - Develop system test plans
 - Coordinate test facilities
 - Develop AIT procedures
 - Lead AIT training activities
 - Lead Test Campaign
 - Test Logistics!
- Payload Working Group
 - Make sure avionics team is aware of payload requirements and payloads understand the satellite program schedule



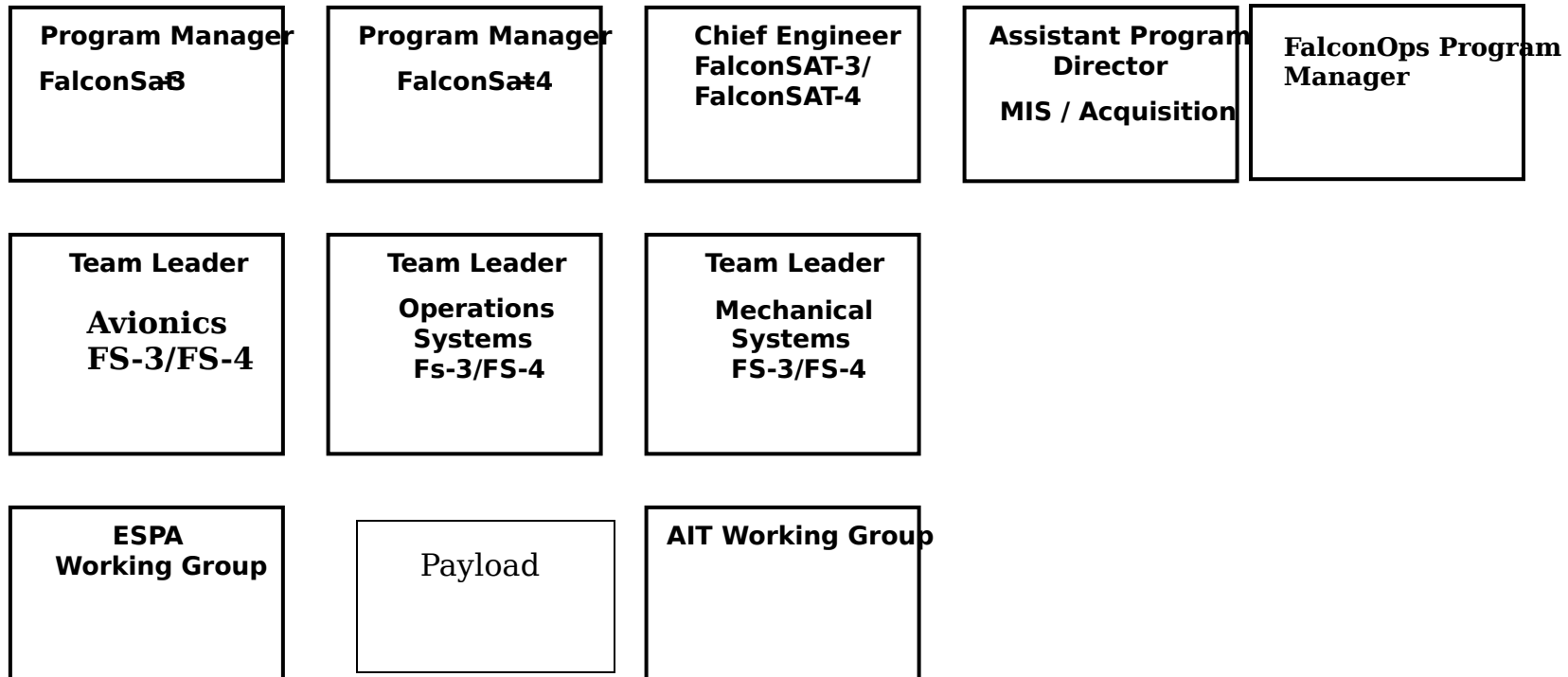
Faculty Organization





Organization

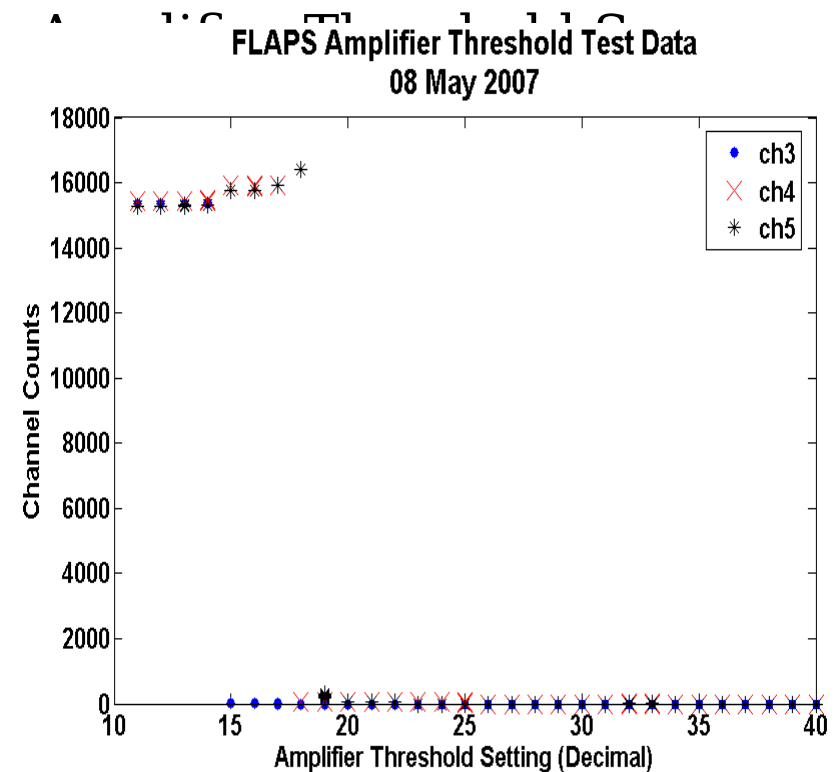
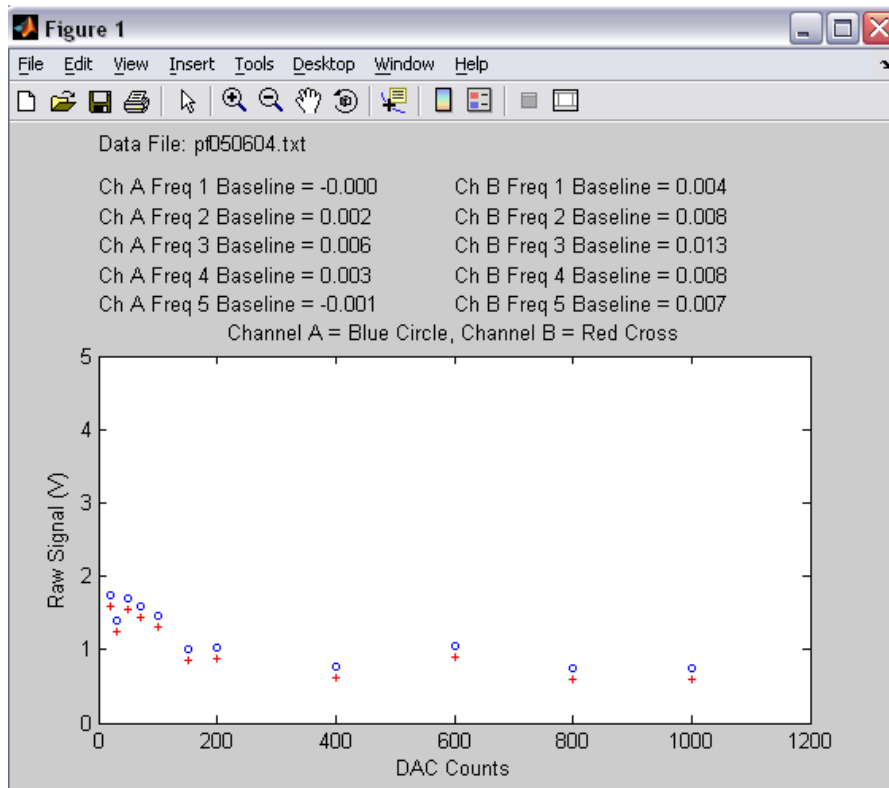
-- Cadets





FS-3 Payload On-Orbit Checkout

PLANE FLAPS





Notable Visitors & Tours

- SECAF
- Head of European Union Space Policy In
- Deputy Undersecretary for DoD Space
- United States Congressman from Minne
- AFRL/VS CC
- Russian Space Forces Four-Star Comm
- Air Force Times
- AFOSR/CC
- French Air Defense Commander
- SpaceX CEO with USAFA/CC and USAFA
- NASA Associate Administrator
- CIA Clandestine Operations Chief
- Air Staff FM
- Dean of Argentinean Air Force Academy
- Various Industry Tours

